EMITTANCE MEASUREMENTS ON FIELD EMITTER DIODES *

Bernhard Kulke and Ronald Kihara

University of California
Lawrence Livermore Laboratory
P. O. Box 808, Livermore, CA. 94550

ABSTRACT

On the basis of time-integrated emittance measurements, several different types of field emitter diodes were investigated at 1-3 kA, 1 MeV. The experimental parameters were the cathode type, the anode mesh texture, the diode spacing and voltage, and the level of collimation of the emerging beam. Over a wide range, the emittance was found to be proportional to the level of collimation. With the diode spacing left fixed, the emittance was found to be essentially independent of the diode voltage and current.

The lowest emittances (30-40 mr-cm at 400 A) were obtained with a foil-type cathode in a ball-over-plane configuration.

INTRODUCTION

The flash x-ray (FXR) linear induction accelerator at Lawrence Livermore Laboratory, currently being designed, requires an injected electron beam of 2-4 kA at 1.5-2 MeV. In order to maximize the forward radiation dose produced by a beam of given diameter, it is essential to minimize the emittance. Field emitter diodes are well suited for flash x-ray applications, but measurements to date of their beam quality have largely been confined to determining the angular divergence of high current beams in the region very close to the anode[1,2]. Measurements on a beam that was collimated and transported over some distance have been reported by the ERA group[3] at Lawrence Berkeley Laboratory (LBL) who utilized a field emitter diode as the injector to a 4 MeV induction LINAC. The proposed FXR electron source is modeled largely after the LBL injector. Thus, in order to confirm and expand on the earlier LBL results, the LBL field emitter diode gun was brought to LLL and reactivated for further emittance measurements.

APPARATUS AND EXPERIMENTAL PROCEDURE

As shown in Figure 1, the diode proper consists of a ball-over-plane or similar configuration with the planar anode formed by tungsten mesh. The electron beam traverses the anode mesh and is focused by a thin lens solenoid that in conjunction with two collimator apertures downstream from the anode, acts as a variable beam scraper. Downstream from the second collimator is mounted a pinhole mask with a square array of 1 mm dia pinholes on 5 mm centers, and this in turn is followed by a scintillator screen carrying a layer of P-11 phosphor.

The diode voltage is generated by five induction modules that are effectively connected in series by the movable cathode stem linking them. This allows convenient adjustment of the anode-cathode spacing. Each module is a ferrite-cored 1:1 pulse transformer, with the single turn primary driven from a nominal 250 kV, 56 ohm, 40 ns Blumlein, and the secondary being formed by the cathode stem. Figure 2 shows some typical pulse shapes. Note that the width of the beam current pulse is narrower after collimation.

To calculate the emittance, the scintillator image (Figure 3) typically was first scanned with a densitometer. The center of each image spot then was used to measure the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1979**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Emittance Measurements On Field Emitter Diodes**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California Lawrence Livermore Laboratory P. 0. Box 808, Livermore, CA. 94550**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT
On the basis of time-integrated emittance measurements, several different types of field emitter diodes were investigated at 1-3 kA, 1 MeV. The experimental parameters'were the cathode type, the anode mesh texture, the diode spacing and voltage, and the level of collimation of the emerging beam. Over a wide range, the emittance was found to be proportional to the level of collimation. With the diode spacing left fixed, the emittance was found to be essentially independent of the diode voltage and current. The lowest emittances (30-40 mr-cm at 400 A) were obtained with a foil-type cathode in a ball-over-plane configuration.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**5**	

angular divergence of each beamlet from the straight-through position. A second angle, calculated from the FWHM of the image spot, represents the growth in diameter of the beamlet over the 115 mm drift distance. The corresponding phase plane representation of any one beamlet was then drawn, and finally, the emittance was calculated as $1/\pi$ times the area of the figure circumscribing the entire phase plane plot.

The diodes investigated here employed a number of different cathodes, with the best one (C1) consisting of a 50 mm dia., approximately spherical, polished stainless steel ball with a small, flush mounted button insert carrying a 7 mm dia. tantalum foil spiral. This was an earlier LBL design. Cathode C2 used a flat, graphite emitter button. Two other cathode geometries employed a graphite rod and a spherical-cap graphite button, respectively. Cathode C3 was a 100 mm dia., polished, stainless steel pancake carrying the 7 mm dia. emitter button of C1.

The experimental anodes consisted of tungsten mesh stretched across a 76 mm dia. circular aperture facing the cathode. They included:

A1. Woven mesh, 0.025 mm dia., in a 0.6 x 1.8 mm array.

A2. Etched mesh, 16 lines/cm, 0.036 mm thick x 0.061 mm wide.

A3. Etched mesh, 24 lines/cm, 0.025 mm thick x 0.05 mm wide.

EXPERIMENTAL RESULTS

The lowest emittances were obtained with the C1 cathode, i.e., a simple ball-over-plane configuration, using a foil emitter. The other cathodes all tended to produce scintillator images that were poorly defined, and clearly represented beams with greater emittance. The measurements discussed in the following therefore concern only cathode C1.

The degree of collimation was controlled throughout by varying the solenoid lens field strength. For diode C1-A1, Figure 4 shows the variation of the emittance vs the collimated beam current with the A-K spacing as the parameter. The nearly linear relationship between the collimated beam fraction and the emittance leads one to conclude that for a beam that is already severely collimated, the remaining beam current is quite uniformly distributed in phase space. A further reduction in beam current thus corresponds linearly to a similar reduction in phase space area, or emittance.

The function of the planar anode mesh is to support a strong electrostatic field at the spherical cathode while at the same time allowing the beam electrons to pass through with minimum interception or perturbation to their trajectories. The perturbing effect of the anode mesh can be modeled by considering each open square as a miniature electrostatic lens, with the focal length given by[4] $f = 4U/(E_2 - E_1)$, where U = anode potential, referred to the cathode, and E_1 and E_2 represent the electric field on the cathode side and on the downstream side, respectively. For the typical case, $E_2 = 0$, the lens is diverging, and the divergence half angle will be proportional to the mesh spacing. Thus, one clearly does well to use the minimum mesh spacing that is consistent with good beam transmission.

In Figure 5 we have plotted the measured emittance variation with current for diode C1-A2 which used the 16 ℓ/cm, etched tungsten mesh. It is seen that the tighter, etched anode mesh does produce somewhat lower emittance beams than the woven mesh of Figure 4. Also, there appears to be a definite minimum of emittance reached near 30 mr-cm. Further measurements[5] indicated that there was nothing to be gained in going from 16 to 24 lines/cm (etched) while there was visible improvement in going from 10 lines/cm (woven) to 16 lines/cm (etched).

In an attempt to gain some insight on the effect of beam voltage variations, the diode potential was changed in three steps, from 680 kV to 970 kV. The results are shown in Figure 6, and clearly, no systematic variation of the emittance with the diode potential is evident. This is as expected, because field emitter diodes at high current levels essentially follow space-charge limited behavior. Under these conditions, the relative potential distribution within the diode, and hence, the electron trajectories and the emittance, should indeed remain unchanged. The focal length of the solenoid lens was essentially kept independent of the beam voltage by adjusting the field strength to produce identical collimation ratios.

SUMMARY AND CONCLUSIONS

Emittance measurements have been carried out on field-emitter diodes to investigate the separate effects of changing the cathode geometry, the anode texture, the A-K spacing, the amount of beam collimation, and the diode potential, respectively. The lowest emittances, i.e., the best quality beams, were obtained with a small-area foil cathode mounted opposite a fine-mesh anode in a ball-over-plane configuration. With beams that were initially collimated to less than one-half the original current, further collimation resulted in a proportional reduction in emittance, but there appeared to be a minimum level below which the emittance could not be reduced.

Variation of the diode potential over a 40% range and of the diode current over an 80% range produced no significant change in the emittance. Extrapolating from this result, emittances on the order of 40-60 mr-cm appear to be realizable even for a 2-4 kA, 1.5 Mev beam.

REFERENCES

1. J. G. Kelly, L. P. Bradley, Pinhole Diagnostics for Direct Measurements of Localized Angular Distributions in Relativistic High Current Electron Beams, SC-RR-72 0058, Sandia Laboratories, (Jan. 1972).
2. L. P. Bradley, Technique to Measure Distribution of Electron Current Density and Electron Trajectories in a High Current Relativistic Electron Beam, Rev. Sci. Instr., 48 pp. 673-676 (June 1975).
3. Glen R. Lambertson et. al., Experiments on Electron Rings at Berkeley, Particle Accel., 5 pp. 113-120, (1973).
4. A. Septier, ed., Focusing of Charged Particles, V. I, p. 296, Academic Press, New York, (1967).
5. B. Kulke and R. Kihara, Emittance Measurements on Field Emitter Diodes, UCRL-82533, Lawrence Livermore Laboratory, (April 5, 1979).

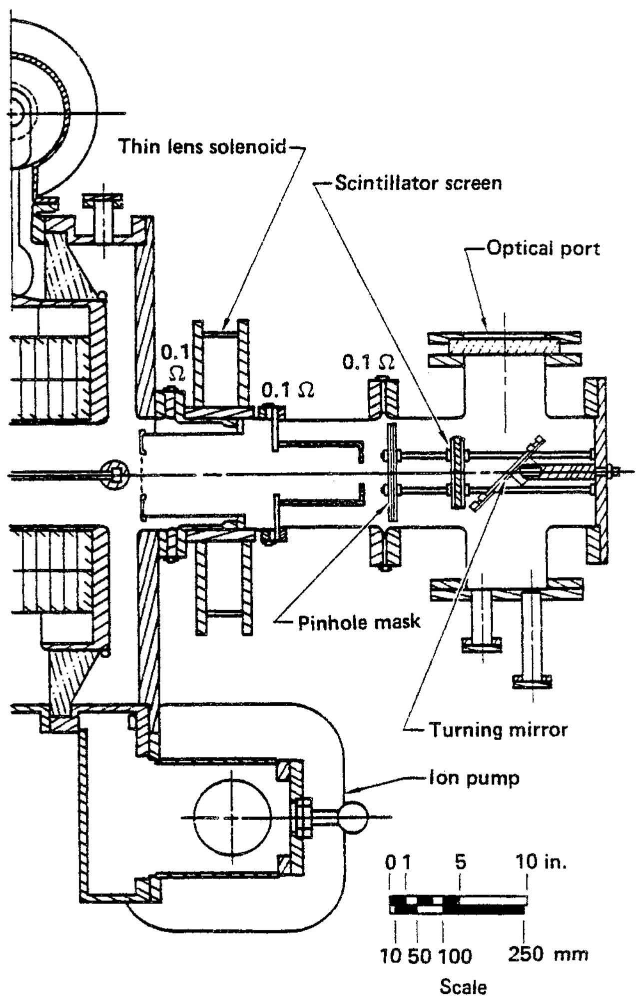

Fig. 1 Field Emitter Diode and Emittance Tester.

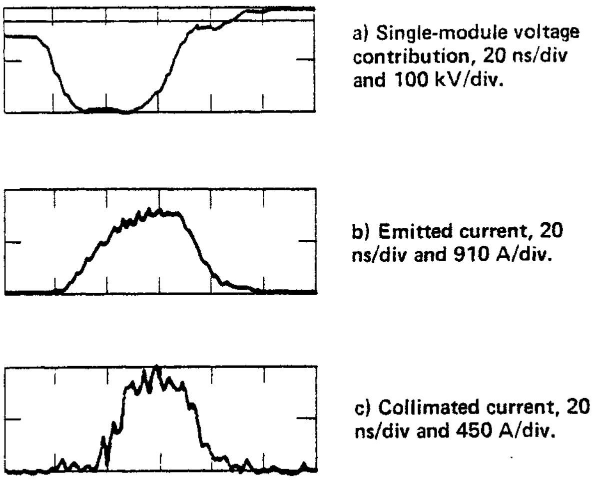

Fig. 2. Typical Voltage and Current Pulses.

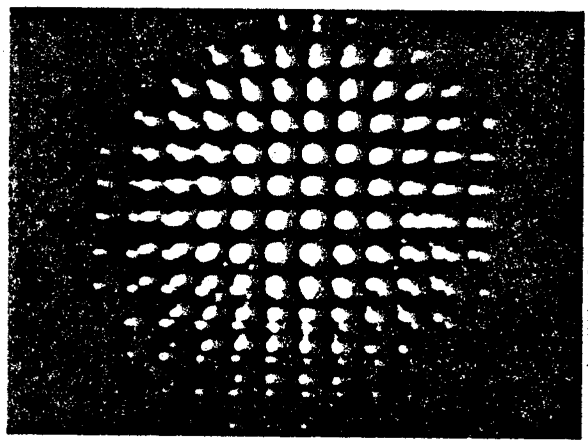

Fig. 3. Scintillator Image Corresponding to a 1460 A Beam Collimated Down to 540 A, at 1 MV. The emittance is 68 mr-cm.

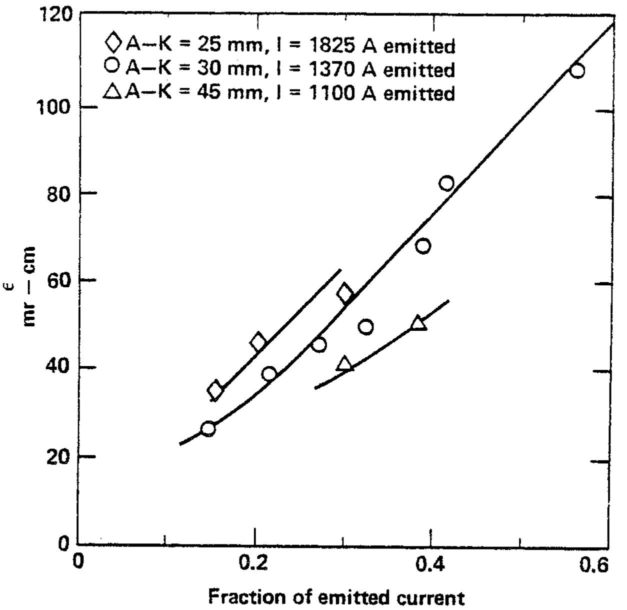

Fig. 4. Emittance vs. Collimation Ratio. Diode C1-A1 at 0.92-1.05 MV. The Parameter is the Diode Spacing.

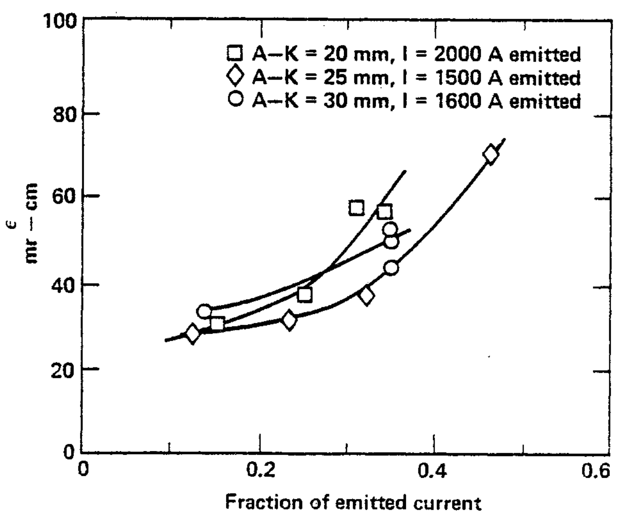

Fig. 5. Emittance vs. Collimation Ratio. Diode C1-A2 at 0.92-1.05 MV. The Parameter is the Diode Spacing.

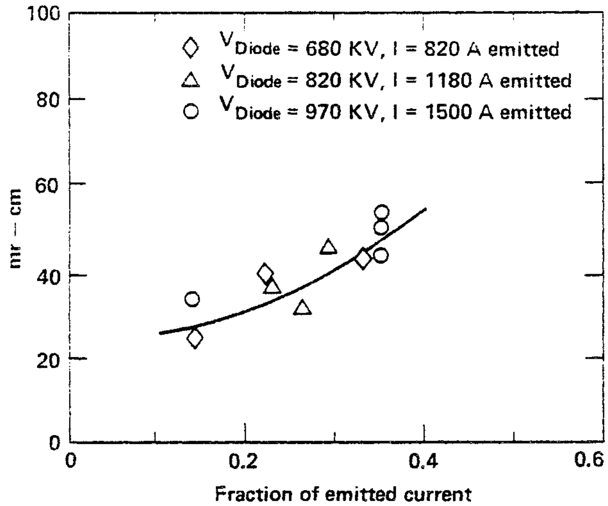

Fig. 6. Emittance vs. Collimation Ratio. Diode C1-A2, A-K = 30 mm. The Parameter is the Diode Voltage.

* "Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48."